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MICRO- AND MACRO-MECHANICAL ANALYSIS OF REV IN SHEARED POLYDISPERSE GRANULAR SAMPLES

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Abstract: A representative elementary volume (REV) is key to ensuring accurate estimations of the mechanical behaviour of granular materials. Guidelines given by testing standards and laboratory equipment restrictions define limits on the maximum particle size (d_{max}) in a triaxial test. The recommended aspect ratio ($\alpha = D/d_{max}$) varies from 5 to 20. However, particle size polydispersity is often ignored in the standards, and its effects on REV estimation are poorly understood. This work studies the combined effects of α and particle size distribution (PSD) on the critical shear strength of granular materials through drained triaxial tests DEM simulations. We found that shear strength increases with α to a maximum value and it stabilizes, indicating a REV. However, better-graded samples stabilize earlier. At the microscopic level, the fraction of particles contributing to stress transmission (N_p^*) shows an effect on shear strength. Finally, for our samples, when α > 12.5 and $N_p^* > 3000$, a REV state is achieved regardless of gradation.

1. Introduction

With the aim of ensuring a reliable mechanical characterization of granular materials, laboratory tests must be carried out on samples having a representative elementary volume (REV). A REV can be defined as the minimum volume needed for it not to affect the behaviour of a sample. Concerning triaxial tests, the approach suggested by international geotechnical testing standards is to fulfil limiting aspect ratios between the height of the sample and its diameter (H/D), and between D and the coarsest particle ($\alpha = D/d_{max}$). Common standards strongly disagree on the minimum α, and the advised values are 5 [1], 6 [2], 10 [3], and 20 [4]. This is particularly relevant in small scaling methods for coarse materials, where the particle size distribution (PSD) must be modified as oversized clasts are removed.

It is well known that PSD does not influence the critical shear strength [5-7]. However, the effects of α have not been deeply studied, neither the influence of the PSD on REV conditions. While there are few studies regarding the aspect ratio for direct shear tests [5, 8] or using 2D numerical simulations [9], the conditions under 3D triaxial loading are poorly understood. Therefore, there is a lack of knowledge in order to thoroughly analyse the suitability of REV conditions recommended by common testing standards. The main objective of this article is to examine how the combination of α and PSD affect the critical shear strength of granular materials.

2. Methodology

We performed 3D DEM simulations of triaxial loading tests on samples composed of spherical grains using the contact dynamics (CD) method [10] implemented in the LMGC90 simulation platform [11]. PSD was controlled by the span ratio $S = (d_{max} - d_{min})/(d_{max} + d_{min})$, where d_{min} is the finest particle diameter in a sample. The ranges of values tested were $\alpha = 5$ to 20, and $S = 0.0$ to 0.6. The PSD is shown in Fig. 1. The number of particles (N_p) in a sample increases rapidly with α and S, from (α, S, N_p) = (5,0, 265) to (α, S, N_p) = (15,0.6, >61000). Samples were prepared in boxes of side $W = 0.1\ m$ and constant ratio $H/W = 2$. The initial disposition of some of the tested samples can be observed in Fig. 2. Triaxial tests were performed in two stages: first, an isotropic compression stage at constant stress $\sigma_0 = 10\ kPa$; second, triaxial quasi-static compression at a constant strain rate until 60% of vertical deformation to reach critical state conditions. More details of the methodology can be found in [12].

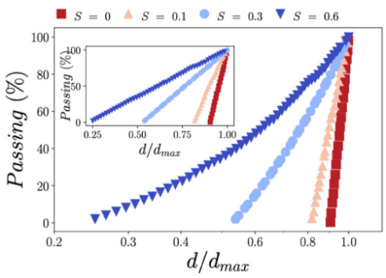

Fig. 1. Normalized PSDs.

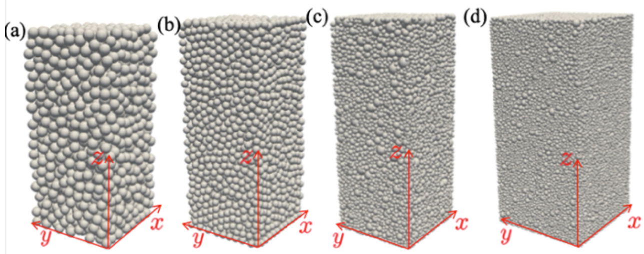

Fig. 2. Snapshots of samples: (a) (α, S) = (10,0), (b) (α, S) = (15, 0), (c) (α, S) = (10, 0.6), (d) (α, S) = (15, 0.6).

3. Results and analysis

We performed macroscopic and microstructural analyses of our results. Fig. 3 presents the normalized shear stress (q/p) and the void ratio (e) for the case S=0.6 and increasing α. Fig. 4 shows that the mean normalized strength averaged in the critical state $\langle q/p \rangle$ and its standard deviation (SD) depend on both α and PSD. While a REV with $\langle q/p \rangle \sim 0.7$ is reached for $\alpha \geq 12.5$ regardless of gradation, for $S = 0.6$ a stable response is observed once $\alpha \geq 8$. It is well known that the critical strength does not depend on PSD [5-7], however, here we show that this is the case only once REV conditions are reached.

The microstructure of the samples at critical state indicates that the number of floating particles (grains not bearing forces) increases with S and α. This can be observed in Fig. 5, where floating particles are displayed in dark violet. Fig. 5 (a) and (b) show, respectively, α = 10 and 15 for S = 0; Fig. 5 (c) and (d) present, respectively, α = 10 and 15 for S = 0.6.

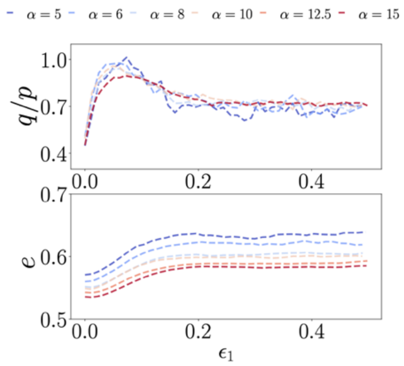

Fig. 3. Normalized shear strength as a function of vertical deformation (S=0.6).

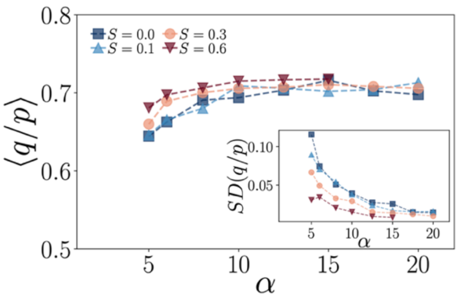

Fig. 4. Mean normalized shear strength at critical state as a function of α for all S.

As illustrated in Fig. 6, the number of engaged grains N_p^* (grains bearing forces) over total particles N_p remains stable with α, but decreases with S. It is worth noting that while the ratio N_p^*/N_p is independent of α at critical state, the number of engaged particles N_p^* vary during the test. Fig. 7 displays $\langle q/p\rangle$ as a function of N_p^*. Surprisingly, all the data collapse into a master curve, and saturate at $\langle q/p\rangle \sim 0.7$ for $N_p^* \geq 3000$. Therefore, for the conditions of the samples tested in this study, REV is attained only if a minimum number of engaged particles are involved in the transmission of forces, regardless of sample size or grading.

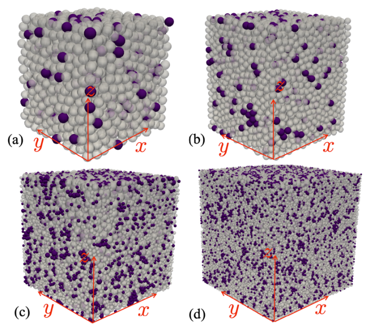

Fig. 5 Samples highlighting non-engaged particles in dark violet: a) (α, S) = (10, 0); b) (α, S) = (15, 0); c) (α, S) = (10, 0.6); d) (α, S) = (15, 0.6)

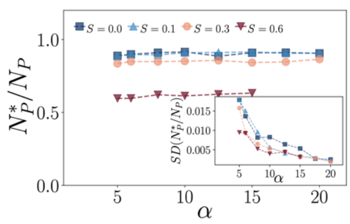

Fig. 6. Proportion of engaged particles in all samples.

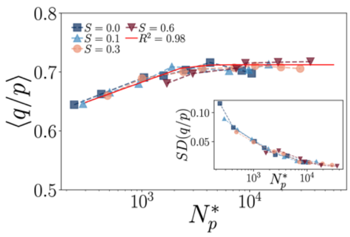

Fig. 7. Critical strength vs. N_p^*.

4. Conclusion

Our study suggests a practical viewpoint, indicating the need to reevaluate the recommendations for REV of granular soil samples in certain widely applied international testing standards for triaxial loading. We found that the minimum aspect ratio should be $\alpha > 12.5$, to ensure REV conditions, which is higher than the value found in different standards [1,2]. These results suggest the necessity for additional research and the collection of experimental data on diverse granular soils to validate the conclusions. From a more fundamental view, the results indicate that for the triaxial loading configuration used here, the number of engaged particles needs to reach a minimum value ($N_p^* > 3000$) to ensure REV conditions, regardless of α and the PSD.

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5. References

[1] British Standards Institution (1990). British standard methods of test for soils for civil engineering purposes. British Standards Institution.

[2] ASTM D7181-20. Standard Test Method for Consolidated Drained Triaxial Compression Test for Soils. West Conshohocken: ASTM International; 2020.

[3] Japanese Geotechnical Society (2020). JGS 0520 Preparation of soil specimens for triaxial tests. Japanese Geotechnical Society.

[4] Japanese Geotechnical Society (2020). JGS 0530 Preparation of specimens of coarse granular materials for triaxial tests. Japanese Geotechnical Society.

[5] D. Cantor and C. Ovalle (2024). Sample size effects on the critical state shear strength of granular materials with varied gradation and the role of column-like local structures. Géotechnique (https://doi.org/10.1680/jgeot.23.00032)

[6] O. Polania, M. Cabrera, M. Renouf, E. Azéma, and N. Estrada (2023). Grain size distribution does not affect the residual shear strength of granular materials: An experimental proof. Phys. Rev. E, 107:L052901.

[7] J. Yang and X. D. Luo (2017). The critical state friction angle of granular materials: does it depend on grading? Acta Geotechnica, 13(3):535-547.

[8] A.B. Cerato and A.J. Lutenegger (2006). Specimen size and scale effects of direct shear box tests of sands. Geotechnical Testing Journal, 29(6):100312.

[9] M.R. Kuhn, K. Bagi (2009). Specimen Size Effect in Discrete Element Simulations of Granular Assemblies. Journal of Engineering Mechanics, Volume 135, Issue 6.

[10] M. Jean (1999). The non-smooth contact dynamics method. Computer Methods in Applied Mechanics and Engineering, 177(3):235–257.

[11] F. Dubois and M. Jean. (2006). The non-smooth contact dynamic method: recent LMGC90 software developments and application. Springer Berlin Heidelberg, Berlin, Heidelberg.

[12] P. Quiroz-Rojo, D. Cantor, M. Renouf, C. Ovalle and E. Azéma (2024). REV assessment of granular materials with varied grading based on macro- and micro-mechanical statistical data. Acta Geotechnica (https://doi.org/10.1007/s11440-024-02498-3)